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Histology in 3D: development of an online interactive student resource on epithelium

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ABSTRACT

Epithelium is an important and highly specialised tissue type that makes up the lining of inner and outer surfaces of the human body. It is proposed that a self-study tool adds to efficient learning and lecturing on this complicated topic in medical curricula. This paper describes the development and evaluation of an online interactive 3D resource on epithelium for undergraduate medical students. A first evaluation was carried out by means of an online survey ($n = 37$). The resource was evaluated positively on the website in general, its visual contents and its value and potential for the medical curriculum.

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Introduction

The physical boundary between the human body and its surroundings is made up of epithelium, a type of tissue that lines body cavities, surfaces and glands (Pawlina & Ross, 2011). Epithelial cells play a crucial role in protection, sensory perception, selective permeability, secretion, absorption and transport of nutrients and waste products (Kerr, 2010).

Medical curricula aim for early clinical experience and have evolved to put a greater emphasis on the acquiring of social and clinical skills, in view of the future profession (Frenk et al., 2010; Weatherall, 2011). This trend has resulted in decreasing numbers of microscopy laboratory sessions (Heidger et al., 2002; Paulsen, Eichhorn, & Brauer, 2010) and reduced contact hours dedicated to histological topics. With a wide range in *a priori* knowledge of students entering these curricula, students need to spend relatively varied amounts of time to master the topic of histology in general and specifically, epithelia. It is proposed that a virtual resource that is available for students at any given time, enabling them to acquire understanding and knowledge of the topic at their own pace, might benefit students. Furthermore, histomicrographs can be overwhelming and confusing to untrained eyes. A more simplified approach to illustrate the structure of tissues may be more easily understood and more engaging for medical students in the pre-clinical years of the curriculum. The combination of this self-directedness with more accessible resources has the potential to be a powerful learning tool.

An important technological innovation to aid multimedia learning in the histology curriculum has been the introduction of virtual slides (Amerongen, 2011; Chen, Lay, Yang, & Chang, 2015; Kumar et al., 2006). This online resource of microscopy images creates an opportunity for students to access histology images outside of class lecture time. Moreover, the dynamic character of the images enhances the self-directed learning performance, compared to static images that could for example be found in text books on the subject (Mione, Valcke, & Cornelissen, 2016).

Since the typically three-dimensional (3D) arrangement of epithelial cells and tissues is closely linked to their functioning, self-explanatory computerised 3D models can make a relevant contribution to students' understanding of the topic, compared to cells and tissues in two-dimensional (2D) representations, such as (virtual) microscopy images (Drapkin, Lindgren, Lopez, & Stabio, 2015). Slide sections, including in virtual microscopy, therefore require students to interpret a range of artefactual changes that occur through cross-sections of a tissue. Several studies report good student feedback on the use of interactive, virtual 3D anatomy models (Codd & Choudhury, 2011; Venail, Deveze, Lallemant, Guevara, & Monaind, 2010). Medical models that allow user control (Estevez, Lindgren, & Bergethon, 2010;

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Meijer & van den Broek, 2010; Nicholson, Chalk, Funnel, & Daniel, 2006; Tam et al., 2010) have been evaluated particularly positively. The positive participant feedback in these studies is in line with the active learning principle in constructivism, namely that the basis for efficient and optimal acquiring of knowledge is active participation of learners (Jonassen & Rohrer-Murphy, 1999). This can be achieved by interactivity. Interactivity with the material that is to be studied has been proven key to simulations in histology (Borkenfeld, Görtler, Kayser, & Kayser, 2011; Chen et al., 2015). Tam et al. (2010) show that virtual 3D models in self-directed learning make supervision or guidance superfluous and enable students to study the topic independently and at their own pace. Self-directed and interactive 3D models are easier to engage with for users and enable a better control of the pace of learning (Yeung, Fung, & Wilson, 2011). Clearly, this requires access to appropriate facilities, including Information Technology (IT) and web-based facilities. This should, however, be available in most modern medical schools.

There are many systems available to reconstruct tissues from histological sections for research purposes and in clinical practice (Capuco, Ellis, Wood, Akers, & Garrett, 2002; Fiala, 2005; Haas & Fischer, 1997; Streicher, Weninger, & Müller, 1997; Streicher et al., 2000). One of the few examples of 3D histology models for educational purposes is the virtual 3D model of the renal corpuscle by Roth, Wilson and Sandig (2015). To address the educational needs of medical undergraduates at the University of Dundee, an online resource was designed and published on www.epithelium3d.com, making it accessible for anyone with an internet connection and a device to display it on.

Materials and methods

The developed resource consists of text content, interactive 3D models, illustrations and links to the virtual microscope of the University of Dundee. All of these were embedded in a website, which was evaluated in an online survey by students and staff involved in the curriculum. Approval was obtained from The Centre of Anatomy and Human Identification's internal ethics board for the project information sheet, consent form and survey questions. For text content and visuals in the resource, reference was made to Kerr (1999, 2010), Kumar et al. (2010), Pawlina and Ross (2011) and Stevens and Lowe (1997). The principles of cognitive theory for multimedia were applied by ensuring all text was accompanied by other media (dual coding), clarifying the topic and referring to corresponding visuals in the text. The resource was built in line with the cognitive theory of multimedia learning, which aims for an efficient acquisition of knowledge (Mayer, 2005). This theory combines visual and textual materials and consists of four principles regarding the acquisition of knowledge (Mayer, 2005):

1. There are verbal and non-verbal information processing channels and these are relatively independent of one another,
2. There is a limited capacity of working memory, but a virtually unlimited capacity of long-term memory,
3. Dual coding enhances learning,
4. In order to construct meaning, learners need to be able to actively process information.

These principles apply in particular to the field of histology, where visuals play a crucial role and a combined use of visual material and text in complementary resources for students has been found to assist learning (Braun & Kearns, 2008; Nivala, De Lange, Rovetti, & Qu, 2012).

Website

The website was made accessible to the public on www.epithelium3d.com, to support access to the resource to as many students as possible. The text content of the resource was tailored to the medical curriculum of the University of Dundee. The website is to be hosted by the University of Dundee. To keep it suited for the curriculum in the years to come, updates to the website and its contents have been anticipated by archiving all relevant files for staff and students of the University of Dundee. This accommodates further developments in the future. The website itself was assembled in Adobe Muse, software that facilitates the creation of websites, while avoiding the writing of scripts. The principles of multimedia theory, mentioned before, were applied to develop the website content. This was done by ensuring interactivity of the content and by combining multiple media when discussing a topic, while aiming to avoid cognitive overload. Three dedicated versions of the website were made, to facilitate specific types of usage; a computer version, a tablet version and a smartphone version. To decrease loading time, corresponding versions of the 3D models were developed at a lower resolution, and embedded on the tablet and phone version of the website. For illustration, screenshots of the tablet and the computer version can be seen in Figure 1. A link to the Virtual Microscope of the University of Dundee was embedded in the computer and tablet version of the website to encourage students to visit the virtual microscopy tool in combination with the resource.

Figure 1. Screenshot of the homepage of the resource as it displays on a smartphone (left), tablet (middle) and computer (right).

Visual content

The creation of the interactive 3D models of the human epithelium required the use of different software programs. The models were based on the text books referenced above and on microscopy images of existing microscopy preparations at the University of Dundee, School of Medicine. The number of 3D models was restricted to exemplify models of five characteristic types of epithelial tissue: epithelial tissue of the bladder, colon, duodenum, skin and trachea. In order to obtain a life-like representation of the tissues, organic modelling was applied. Pixologic ZBrush 4R7 was used to model the tissues. Textures on the models were created by digital painting and overlaying textures from histology slides, obtained from the University of Dundee, School of Medicine. Stages of this process are visualised in Figure 2.

In order to enable interactive viewing of the 3D models, they were uploaded to an interactive 3D viewing platform www.sketchfab.com and annotated. In addition, to stimulate active processing of information, self-assessment versions of the models (without annotations) were uploaded. The final result is shown in Figure 3.

To provide further context for models and text content, various illustrations were created. To improve understanding and recognition of tissues shown under a microscope, the microscopy illustrations were not created *de novo*. Instead photographs of histology slides were used as a foundation. Illustrations for further clarification of structures or components of the epithelial models as well as the banners for the website were based on screen shots of the online models, which were then further modified, using Adobe Photoshop and Adobe Illustrator CC. Colours from the colour scheme of the University of Dundee website were used to achieve a cohesive design for the website.

Survey

To evaluate the resource, an anonymous online qualitative feedback survey was sent out to undergraduate medicine students and staff involved in the curriculum. Participants were directed to the resource by a link. Upon visiting the resource, participants would return to the survey to evaluate the resource. The survey included questions regarding the participant, the resource in general, the 3D models, the illustrations, and the added value and potential of the resource for the curriculum.

Results

A total of 37 respondents completed the survey (22 female, 15 male). Out of these 37 respondents, 32 were medical students, ranging from first to fifth year (approximately 50% in the second year). The other participants were involved in health care and/or the medical curriculum. The majority (59.4%) stated they had visited all sections of the website. Time spent on the website varied from three to more than 20 min, with 11–15 min as both mean and median time span. To a free-text question, 36 participants gave a general impression of the website. Ten respondents appreciated its user-friendliness, five its

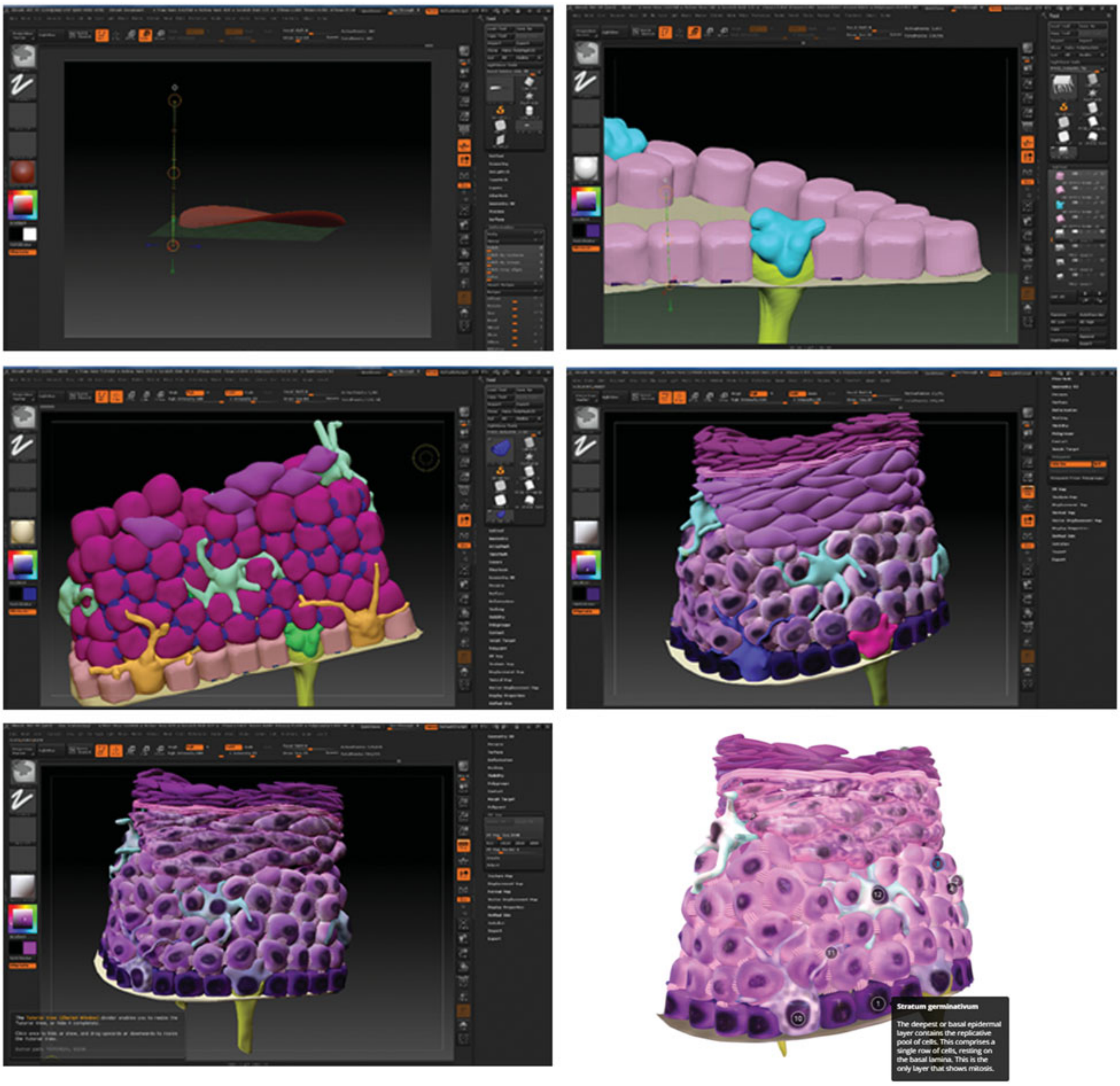

Figure 2. Stages of the process of modelling a tissue, upper row and middle left: modelling the individual cells. Middle right and lower left: painting the cells; lower right: final annotated model.

value to existing teaching material and 11 its aesthetics. More specifically, respondents were asked to rate aesthetics, user-friendliness and navigability, organisation of the resource and presentation of information (Figure 4).

As far as the interactive 3D models are concerned, the results are shown in Figure 5. Regarding the 2D visualisations incorporated in the website, on the whole, feedback was positive, both in terms of additional value to understanding of the subject and helpfulness of the amount of detail on the illustration. This can be seen in Figure 6. Figure 7 shows how the suitability to the medical curriculum and value to the students is evaluated.

Regarding improvements to the resource, it was suggested to add models displaying (disease) processes. In addition, the suggestion was made to elaborate on the information given in the accompanying text. In a few cases, viewing the models was hindered by a slowed response to navigation. Finally, it was suggested to make the information concise by using bullet points, to integrate different levels of complexity to accommodate different years in the curriculum and to add audio. A few comments concerned improvement of the website interface by enriching its design and making it more dynamic.

Discussion

An important note to make concerning the evaluation is that the participants were asked for their opinion on the usefulness of the resource but were not tested on the knowledge acquired when using the resource. A comparison of student knowledge

Figure 3. The models as they were embedded in the resource. Clockwise, starting top left: epithelium of the skin, colon, trachea, duodenum and bladder.

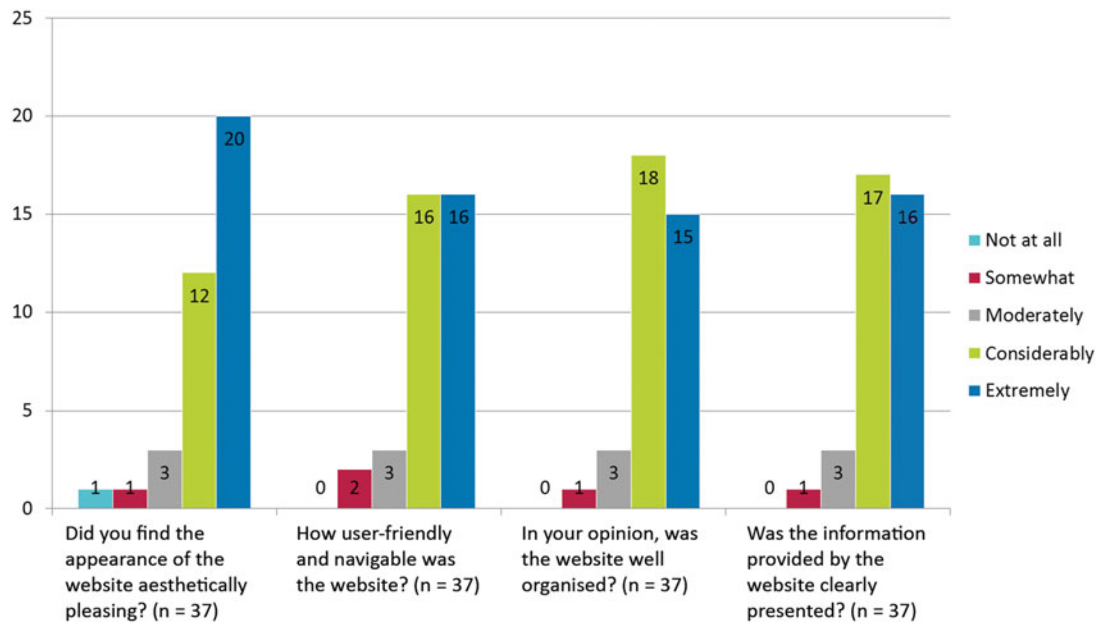

Figure 4. Evaluation of the website.

prior to and after use of this resource, compared to that of existing tools, would provide valuable information. For future development, such a test is recommended with a sample population large enough to represent the medical undergraduates of the University of Dundee, School of Medicine.

The reviews suggest improvements to the website interface. This shows the benefits of student feedback early in the process of web design. The website could be further improved by assessment of user behaviour within the resource. Participants suggested inclusion of (disease) processes. This could be

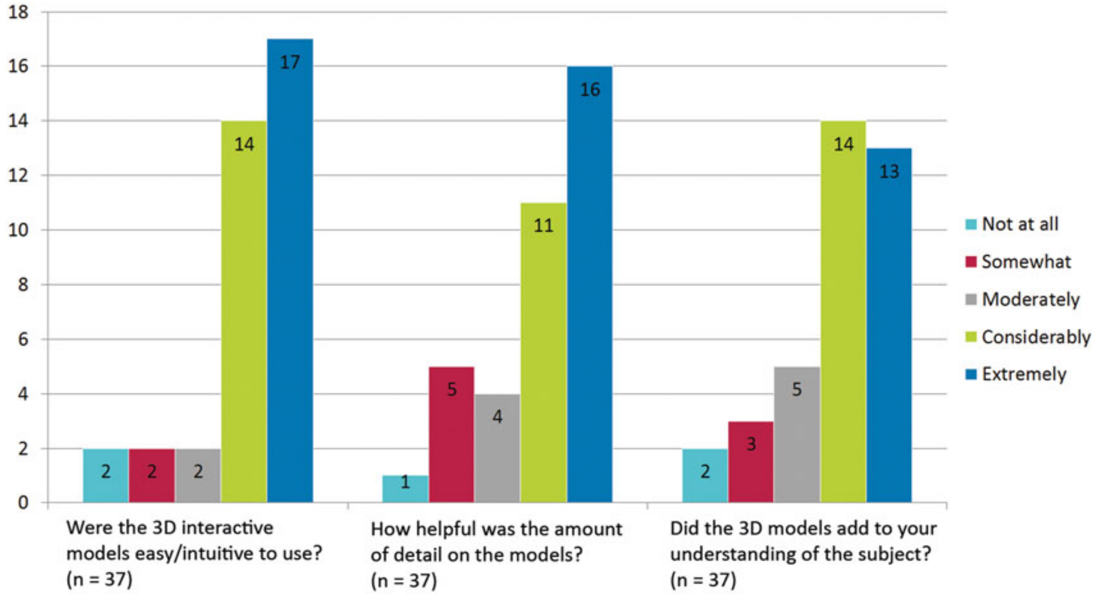

Figure 5. Evaluation of the 3D models.

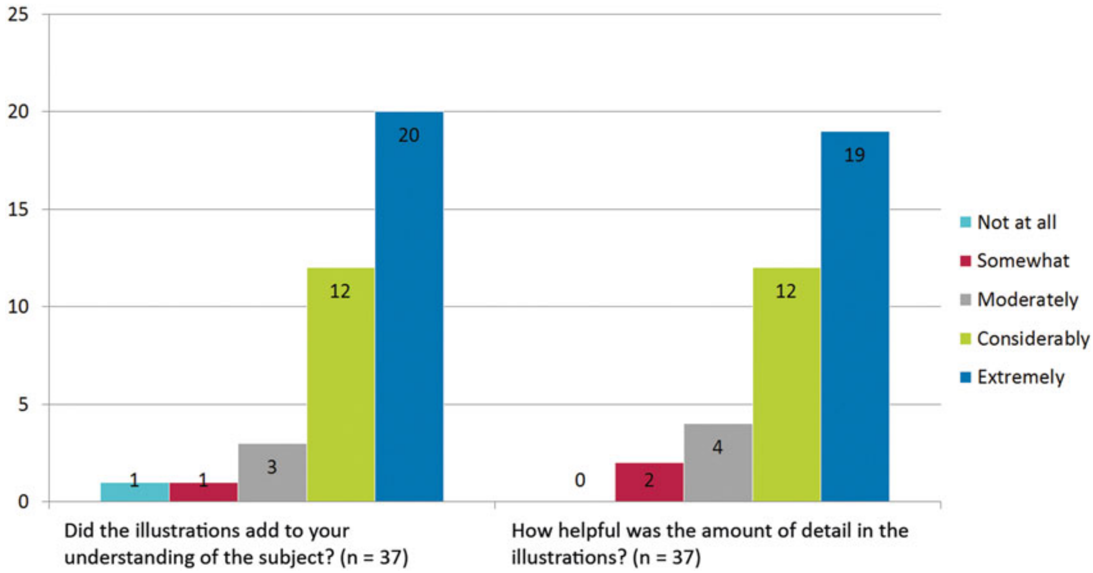

Figure 6. Evaluation of illustrations.

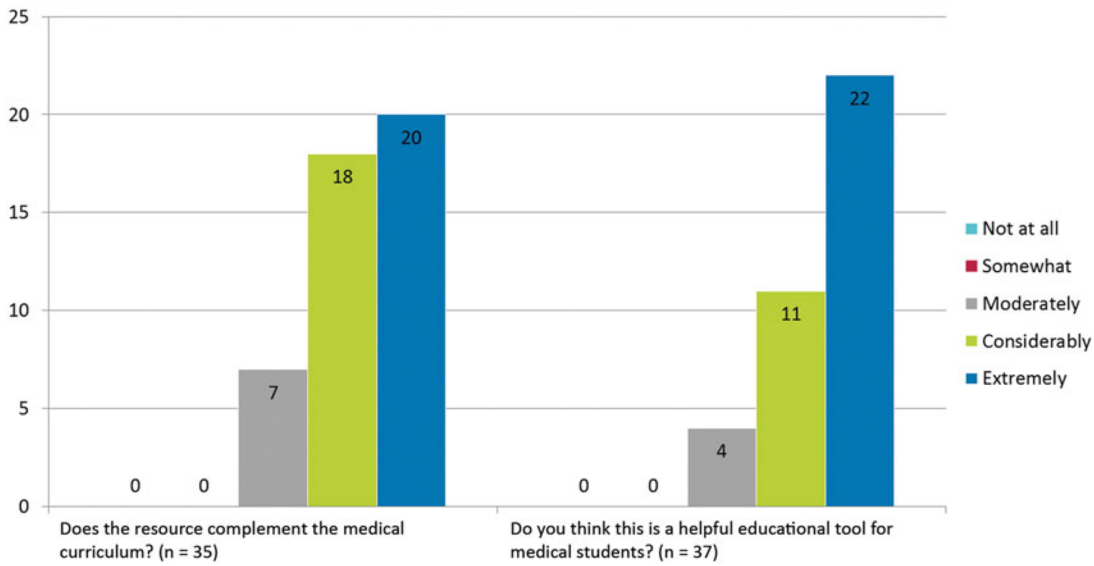

Figure 7. Evaluation of the applicability and suitability of the resource.

achieved by integrating animation in interactive 3D models.

Conclusion

This project aimed to bridge the gap between microscopy images and the 3D tissues they represent by means of interactive 3D models. An interactive e-learning tool was developed for medical undergraduates of the University of Dundee. The tool was customised for computer, tablet and smartphone. Based on a brief survey, the resource was valued as a relevant aid for the education and training in histology. With regards to the developed 3D models, there is a need to further downscale file sizes in order to decrease loading time of the interactive 3D viewer, especially on tablets and mobile devices. It might also be worthwhile considering animating cells in the 3D models and using audio in the resource. The resource focused on five exemplary epithelial tissues. The survey indicated that more tissues could be included in the resource, as well as disease processes manifesting in these tissues. This confirms the potential of the e-learning tool as developed; indicating that further visualisation of other types of cell tissues through 3D modelling is worth being taken into consideration.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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